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# Critical Nitrogen Level in Petioles of Papaya

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## INTRODUCTION

In an earlier study at Waimanalo, on the Island of Oahu, Hawaii *(2)*, a tentative petiole N level for maximum yield of papaya was determined. A study was then conducted at Puna, Island of Hawaii *(5)*, to confirm this N level. The N level determined at Puna was higher than that determined at Waimanalo. Since petiole N concentrations were more highly correlated to fruit yield in the study at Puna than in that at Waimanalo, it appeared that the N level determined at Puna was more precise than that at Waimanalo.

This study is an extension of the work started at Waimanalo and continued at Puna. The objective was to establish the petiole N level with greater precision. Other variables besides petiole N which were found to affect fruit yield at Puna *(5)* were also studied under conditions at Waimanalo.

## MATERIALS AND METHODS

Papaya plants, *Carica papaya* L. cv. Solo, were grown in "jiffy" pots from seeds until they were 2.4 months old. The plants were then transplanted to the field into holes which were dug in an 8 X 10 foot planting scheme. Two plants were placed in each hole and grown until they flowered at an age of 7 months. The sex of each plant was then identified, one hermaphroditic plant was left in each hole, and treatments were initiated.

Nitrogen was applied to each tree as ANS-30[1] fertilizer at 12-week intervals in the following amounts, in pounds: treatment A, 0.0; B, 0.07; C, 0.14; D, 0.28; E, 0.56. Potassium as muriate of potash was applied

[1]Refers to ammonium-nitrate-sulfate composed of 12.3% nitrate-N and 17.7% ammonium-N, with 0.43% P.

to each tree at 12-week intervals at the rate of 0.274 lb. K. Phosphorus was applied to each tree as superphosphate, in the amounts of 0.496 lb. P at transplanting time and 0.460 lb. P when trees were 16 months old. The superphosphate was applied at the bottom of each planting hole at transplanting time, while at the fruiting stage it was applied in four shallow holes in a circular pattern about 3 feet from the tree trunk. Nitrogen and K fertilizers were buried in three shallow holes around the tree.

Each treatment was replicated 6 times in randomized block design. Each plot had two to four hermaphroditic trees, with most plots having four. Only one plot had two hermaphroditic trees. Guard rows and guard trees separated plots from each other.

The orchard was located at an elevation of about 90 feet. This area is moderately windy, especially during the summer. During the summer the days were hot and the nights were warm (Table 1). Rainfall between March and November in 1969, and between February and October in 1970, was low. Hail damaged and removed about 35 percent of the tree leaves on January 31, 1969.

In 1969, irrigation was started on March 2nd and continued until November 28th, at 10-day intervals, more or less. In 1970, irrigation was started on March 2nd and continued until October 14th. Trees were irrigated by means of shallow but wide furrows, 175 feet long, which were situated on one side of the row.

The soil in the orchard belonged to the gray hydromorphic group whose clay is composed of montmorillonite and hydrated halloysite. It had a moderately high cation-exchange and buffering capacities.

The tree-trunk circumference was measured at a marked point about 6 inches from the ground at the beginning of the experiment and at 12-week intervals thereafter. The fresh and dry weights of the petioles, which were sampled for the nutrient analyses, also served as the growth indexes. The tree-trunk circumference is an index of tree size and is associated with the fruit yield capacity of the tree. The weight of the petiole appears to be related to the vegetative growth rate of the tree.

Matured fruits of the marketable solo and the carpellodic types were harvested, and fruits of each type were counted and weighed by plots at weekly intervals from April 18, 1969 to October 15, 1970. The weight of each type of harvested fruit was expressed on a per tree basis.

The recently matured petioles were sampled 5 times throughout the study for chemical determinations of nutrients. Two petioles, one from each tree, were collected from trees in each plot and constituted a sample. The preparation of the samples for chemical analyses and the chemical procedures were the same as described earlier *(4)*.

**Table 1. Mean monthly air temperature and monthly rainfall records at Waimanalo during the study**

| Month | Temp F | | Rain, inches | Month | Temp F | | Rain, inches |
|---|---|---|---|---|---|---|---|
| | Max | Min | | | Max | Min | |
| December 1968 | 79.1 | 68.7 | 15.4 | December 1969 | 80.1 | 65.8 | 5.4 |
| January 1969 | 77.0 | 62.4 | 11.4 | January 1970 | 78.8 | 64.1 | 8.6 |
| February 1969 | 76.2 | 68.8 | 5.3 | February 1970 | 78.4 | 62.6 | 2.0 |
| March 1969 | 78.1 | 68.7 | 3.4 | March 1970 | 79.3 | 66.4 | 0.7 |
| April 1969 | 78.7 | 67.3 | 1.6 | April 1970 | 79.8 | 68.7 | 7.5 |
| May 1969 | 82.7 | 73.5 | 2.6 | May 1970 | 81.9 | 71.0 | 1.2 |
| June 1969 | 85.1 | 71.7 | 1.1 | June 1970 | 83.2 | 72.3 | 0.5 |
| July 1969 | 84.4 | 74.0 | 1.9 | July 1970 | 84.2 | 72.1 | 1.9 |
| August 1969 | 85.7 | 75.2 | 0.7 | August 1970 | 85.4 | 72.5 | 1.3 |
| September 1969 | 84.2 | 73.9 | 1.6 | September 1970 | 85.6 | 71.9 | 1.0 |
| October 1969 | 84.3 | 69.6 | 1.1 | October 1970 | 83.3 | 72.0 | 4.7 |
| November 1969 | 82.3 | 68.6 | 2.4 | | | | |

**Table 2. The effect of N fertilization on the growth rate of the tree-trunk circumference[x]**

| Treatment | Tree-trunk circumference (cm) 12/6/68 | Growth rate, mm/day[y] | | | | |
|---|---|---|---|---|---|---|
| | | 12/6/68-3/4/69 | 3/4/69-5/26/69 | 5/26/69-8/19/69 | 8/19/69-11/11/69 | |
| | | Unadjusted | Unadjusted | Unadjusted | Unadjusted | Adjusted |
| A | 27.3 a | 1.49 a | 0.56 a | 0.06 a | 0.17 a | 0.20 a |
| B | 27.7 a | 1.48 a | 0.56 a | 0.11 a | 0.35 bc | 0.36 b |
| C | 28.4 a | 1.42 a | 0.49 a | 0.08 a | 0.35 bc | 0.35 b |
| D | 28.6 a | 1.45 a | 0.46 a | 0.10 a | 0.44 c | 0.43 b |
| E | 29.3 a | 1.51 a | 0.50 a | 0.07 a | 0.45 c | 0.42 b |
| C.V.[z] | 7.9 | 8.0 | 29.8 | 63.8 | 23.5 | 19.4 |

(See footnotes at end of table.)

**Table 2.** *(Continued)*

| Treatment | Tree-trunk circumference (cm) 12/6/68 | Growth rate, mm/day[y] | | | | | |
|---|---|---|---|---|---|---|---|
| | | 11/11/69-2/3/70 | | 2/3/70-4/28/70 | | 4/28/70-7/21/70 | 7/21/70-10/14/70 |
| | | Unadjusted | Adjusted | Unadjusted | Adjusted | Unadjusted | Unadjusted |
| A | 27.3 a | 0.33 a | 0.31 a | 0.10 a | 0.08 a | 0.01 a | 0.01 a |
| B | 27.7 a | 0.42 ab | 0.41 ab | 0.13 ab | 0.12 b | 0.04 ab | 0.07 b |
| C | 28.4 a | 0.52 bc | 0.52 bc | 0.17 bc | 0.18 cd | 0.06 b | 0.09 bc |
| D | 28.6 a | 0.60 c | 0.61 c | 0.18 bc | 0.19 de | 0.08 b | 0.17 d |
| E | 29.3 a | 0.64 c | 0.66 c | 0.20 c | 0.22 e | 0.05 b | 0.13 cd |
| C.V.[z] | 7.9 | 23.3 | 22.1 | 26.3 | 21.4 | 66.6 | 50.5 |

[x]Means in a column with different letters are significant at the 5% level.

[y]Adjusted growth rates after 4/28/70 are not presented because the error mean square was not reduced when covariance analysis was applied to the data.

[z]Coefficient of variation.

The statistical procedures described by Snedecor *(9)* were followed, and the multiple range test *(7)* was used to test the significance of the treatment means after variance or covariance analyses were applied to the data. The method of multiple regression was used to evaluate the effects of some variables on fruit yield. Since there was evidence that all the trees in plots at the end of the irrigation furrows did not receive as much water as the others, as indicated by the growth and yield data, the data from these plots were not used in the calibrations of petiole N to fruit yield and the N application rate to fruit yield.

## RESULTS AND DISCUSSION

### Growth Rate of the Tree Trunk and Weight of Petioles

The growth rate of the tree-trunk circumference was high at the start of treatments when trees were flowering, but became lower when the trees began to fruit (Table 2). Trees grew at a much slower rate during the summer than during the winter, which suggests that they were under moisture stress during the summer.

Significant differences among treatments in tree-trunk growth rate were obtained about 9 months after the start of treatments (Table 2). The damage to the leaves by the hail, after start of treatments, may have delayed growth and yield responses. Trees which were supplied N at the two high rates grew the fastest.

Initial tree size influenced tree-trunk growth rates from August 19, 1969 to April 28, 1970, but did not influence them at the last two measurement dates (Table 2). This is in agreement with results obtained previously *(5)*.

Petioles from trees supplied with N at all rates were heavier than those not supplied any N (Table 3). Petioles sampled on October 7 and December 16 weighed substantially more than those sampled during the summer, which suggests, as in the tree-trunk growth rate, that the trees were under moisture stress during the summer.

### Fruit Yield

Trees which were supplied N at all rates gave higher yields of the solo type of fruit than those not supplied N (Table 4). In the first year of production, only trees from treatment B gave significantly higher yields than those not supplied N, although trees from treatments C, D, and E each gave yields which were higher than those from treatment A. During the 6 months of the second year, all trees supplied with N gave higher yields than those not supplied. There was no significant differ-

**Table 3. The effect of N fertilization on petiole weights**

| Treatment | Sampling date | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 8/12/69 | | 10/7/69 | | 12/16/69 | | 6/9/70 | | 7/14/70 | |
| | Weight, g[x] | | Weight, g | | Weight, g | | Weight, g | | Weight, g | |
| | Fresh | Dry | Fresh | Dry | Fresh | Dry | Fresh | Dry | Fresh | Dry |
| A | 66.8 a | 7.2 a | 75.7 a | 8.6 a | 81.8 a | 8.7 a | 32.7 a | 3.5 a | 40.8 a | 4.4 a |
| B | 87.9 a | 9.6 a | 104.2 b | 11.8 bc | 99.6 b | 10.5 b | 54.1 b | 5.8 b | 66.2 b | 7.2 b |
| C | 78.6 a | 8.7 a | 103.6 b | 11.5 b | 100.7 b | 10.8 b | 60.5 b | 6.5 b | 85.0 c | 9.5 c |
| D | 86.5 a | 9.7 a | 106.7 b | 12.2 bc | 110.0 bc | 11.9 bc | 68.2 b | 7.5 b | 96.5 c | 10.9 c |
| E | 86.2 a | 9.7 a | 114.8 b | 13.5 c | 116.3 c | 12.6 c | 68.4 b | 7.7 b | 98.7 c | 11.2 c |
| C.V.[z] | 20.7 | 21.5 | 12.6 | 11.4 | 9.6 | 10.4 | 26.9 | 28.7 | 18.0 | 17.8 |

[x]Means in a column with different letters are significant at the 5% level.

[z]Coefficient of variation.

ence among trees supplied with N at the various rates, but those supplied higher rates gave higher yields.

The yield of the solo type of fruit during the first year of production was low when compared to that during the 6-month period of the second year. Again, this may have resulted from defoliations of the trees caused by the hailstorm in January 1969.

The yields from plots situated at the ends of the irrigation furrows were lower than those from plots of the same treatment nearer the source of irrigation water, possibly because the trees of plots at the former did not receive as much water as those of plots at the latter.

**Table 4. The effect of N fertilization on fruit yield[x]**

| Treatment | Tree-trunk circumf. (cm) 12/6/68 | Yield, lb/tree[y] | | | | |
|---|---|---|---|---|---|---|
| | | 4/18/69-4/16/70 | | | 4/23/70-10/15/70 | |
| | | Solo | | Carpels | Solo | Carpels |
| | | Unadjusted | Adjusted | Unadjusted | Unadjusted | Unadjusted |
| A | 27.3 a | 79.3 a | 86.4 a | 9.2 a | 64.8 a | 1.5 a |
| B | 27.7 a | 116.0 b | 119.2 b | 9.2 a | 101.2 b | 2.2 ab |
| C | 28.4 a | 100.1 ab | 99.1 ab | 9.2 a | 102.9 b | 4.2 bc |
| D | 28.6 a | 109.2 b | 106.8 ab | 6.0 b | 121.8 b | 3.0 abc |
| E | 29.3 a | 112.8 b | 106.0 ab | 7.3 ab | 124.3 b | 4.9 c |
| C.V.[z] | 7.9 | 19.9 | 15.3 | 28.4 | 18.1 | 61.6 |

[x]Means in a column with different letters are significant at the 5% level.

[y]Adjusted yields are presented only when the error mean square was reduced in covariance analysis.

[z]Coefficient of variation.

## Fruit Weight and Fruit Soluble Solids

During the first year of production, the average weights of each harvested fruit did not vary significantly among treatments (Table 5). However, the average weight of fruit from treatment A was less than that of the other treatments. During the 6 months of the second year, harvested fruits on the average weighed more with increased N application rates, until the peak was reached at treatment D; it declined at the highest N rate.

The soluble solids content of the fruit at the early part of the fruit-harvesting season tended to be lower when trees were given N. But

**Table 5. Effects of N fertilization on the mean weight of harvested fruits and on fruit soluble solids[x]**

| Treatment | Mean fruit wt (lb.) | | % total soluble solids | |
|---|---|---|---|---|
| | 4/18/69-4/16/70 | 4/23/70-10/15/70 | 11/9/69 | 5/11/70 |
| A | 1.04 a | 1.03 a | 14.1 ab | 13.0 a |
| B | 1.10 a | 1.11 ab | 14.4 a | 13.8 b |
| C | 1.08 a | 1.14 b | 13.8 ab | 13.8 b |
| D | 1.05 a | 1.16 b | 13.4 b | 13.9 b |
| E | 1.08 a | 1.12 ab | 13.7 ab | 14.0 b |
| C.V.[z] | 6.2 | 7.1 | 4.3 | 4.1 |

[x]Means in a column with different letters are significant at the 5% level.

[z]Coefficient of variation.

when the trees became older, the soluble solids content of the fruits from trees supplied N was higher than those not supplied N. It appears that if the papaya trees are deficient in N for some time, the capacity of the trees to photosynthesize becomes less than that of trees given adequate N, possibly because the leaves are smaller.

## Petiole Nutrient Composition and Petiole Moisture

The petiole N concentrations were generally high in the December samples and low in the June and July samples (Table 6). The petiole N concentrations in the latter samples may have resulted from the low soil moisture supply at this time of the year, as suggested by the growth rate of the tree trunk (Table 2) and the weight of the petioles (Table 3). The low petiole N concentrations may also have been in part due to the action of petiole K concentrations, since in papaya, high K tends to lower N in the petioles *(4)*. The high petiole N concentrations from trees supplied high N rates were generally accompanied by lower P and K concentrations. This may have resulted from greater growth dilution and greater amounts of nutrients removed from harvested fruits.

The petiole P concentrations were generally high in trees not supplied any N as compared to those supplied N (Table 6), resulting probably from accumulations because of less vegetative growth and less fruit-set. The petiole P concentrations were generally above the tentative P level *(3)*, except in treatment E of the June sample, where the P concentration was below the critical level. High petiole N tended to lower petiole P as found at Puna *(5)*.

Table 6. Effects of N fertilization on petiole nutrient composition and water[x]

| Sampling date | Treatment | % petiole moisture | % of dry petiole | | | | |
|---|---|---|---|---|---|---|---|
| | | | N | P | K | Ca | Mg |
| 8/12/69 | A | 89.23 a | 0.93 a | 0.237 a | 4.91 a | 1.67 a | 0.72 a |
| | B | 89.08 ab | 1.08 b | 0.228 a | 4.70 a | 1.71 a | 0.67 a |
| | C | 88.97 ab | 1.11 b | 0.214 a | 4.66 a | 1.60 a | 0.70 a |
| | D | 88.80 b | 1.16 bc | 0.221 a | 4.27 a | 1.62 a | 0.70 a |
| | E | 88.78 b | 1.27 c | 0.222 a | 4.52 a | 1.50 a | 0.63 a |
| | C.V.[z] | 0.29 | 7.4 | 10.8 | 8.7 | 7.5 | 15.0 |
| 10/7/69 | A | 88.72 a | 0.87 a | 0.267 a | 4.47 a | 1.70 a | 0.51 a |
| | B | 88.72 a | 1.01 b | 0.238 a | 4.30 a | 1.61 a | 0.48 a |
| | C | 88.92 a | 1.11 c | 0.248 a | 4.47 a | 1.51 ab | 0.48 a |
| | D | 88.50 a | 1.14 c | 0.236 a | 3.90 ab | 1.51 ab | 0.48 a |
| | E | 88.55 a | 1.24 d | 0.238 a | 3.86 b | 1.45 b | 0.48 a |
| | C.V.[z] | 0.36 | 6.4 | 12.0 | 8.4 | 7.8 | 9.3 |
| 12/16/69 | A | 89.32 a | 0.89 a | 0.285 a | 4.40 a | 1.54 a | 0.44 a |
| | B | 89.45 a | 1.11 b | 0.241 b | 4.71 a | 1.33 ab | 0.41 a |
| | C | 89.25 a | 1.12 b | 0.221 b | 4.09 a | 1.26 b | 0.39 a |
| | D | 89.17 a | 1.24 c | 0.224 b | 3.97 a | 1.13 b | 0.39 a |
| | E | 89.13 a | 1.34 c | 0.218 b | 3.98 a | 1.11 b | 0.37 a |
| | C.V.[z] | 0.36 | 7.8 | 8.8 | 11.7 | 14.4 | 12.1 |
| 6/9/70 | A | 89.22 a | 0.82 a | 0.377 a | 4.52 ab | 1.90 a | 0.80 a |
| | B | 89.33 a | 0.88 a | 0.263 b | 4.56 a | 2.05 a | 0.81 a |
| | C | 89.25 a | 1.02 b | 0.229 c | 4.14 b | 2.00 a | 0.77 a |
| | D | 89.10 a | 1.14 c | 0.217 cd | 3.76 bc | 2.00 a | 0.82 a |
| | E | 88.73 b | 1.18 c | 0.192 d | 3.53 c | 1.93 a | 0.74 a |
| | C.V.[z] | 0.35 | 7.8 | 8.5 | 7.9 | 7.2 | 11.1 |
| 7/14/70 | A | 89.25 a | 0.83 a | 0.395 a | 4.84 a | 1.76 a | 0.75 a |
| | B | 89.18 a | 0.92 b | 0.293 b | 4.80 a | 1.71 a | 0.70 ab |
| | C | 88.85 ab | 1.04 c | 0.270 bc | 4.10 b | 1.68 a | 0.64 ab |
| | D | 88.75 b | 1.17 d | 0.255 bc | 3.67 b | 1.72 a | 0.68 ab |
| | E | 88.60 b | 1.25 e | 0.241 c | 3.66 b | 1.61 a | 0.59 b |
| | C.V.[z] | 0.38 | 6.2 | 11.5 | 9.1 | 10.5 | 13.6 |

[x]Means in a column with different letters are significant at the 5% level.

[z]Coefficient of variation.

The petiole K concentrations were higher in trees not supplied N as compared to those supplied N. In general, the K concentrations were well above the tentative critical level (2.85%) for this nutrient *(4)*.

The petiole Ca concentrations were generally higher in trees in this study than those at Puna *(5)*. In general, they were higher in petioles sampled during the summer than those sampled during the winter, suggesting that the growth rate of the trees may have been relatively lower than the rate of Ca uptake during the summer.

The petiole Mg concentrations, as with Ca, were much higher in these samples than those at Puna *(5)*, the result of a higher supply of these nutrients at Waimanalo than at Puna. There was no relation between the petiole concentrations of N and Mg, in contrast to that observed at Puna where petiole N and petiole Mg were correlated. This may be because of the high Mg supply at this locality, which agrees with the results of Neff et al. *(8)*, since they too observed no significant relation between N and leaf Mg when the supply of the latter was in excess of needs for plant growth.

The concentration of petiole moisture tended to be lower as trees were supplied increasing increments of N fertilizer. However, petiole moisture was highest in petioles sampled in December, a period when rainfall was more plentiful, days were shorter, and the air temperature was lower than at the other leaf sampling periods.

**Plant Deficiency Symptoms**

When trees were not supplied N, leaf blades at all stages of maturity were yellow by September 1969, 9 months after the start of treatments. The reddish color of petioles from trees under low N supply observed at Puna *(5)* was not detected in this study, possibly because the petiole N concentration of trees under low N supply was not as low as that at Puna. Fruit-set in trees not supplied any N was poor.

**Relations of Some Variables to Fruit Yield**

Petiole N and the square of the petiole N accounted for 76 percent of the variance of yield taken from February 19 to June 4, 1970 (Table 7). In addition to petiole N, tree-trunk size and petiole weight were the two other significant variables. These two variables were equally important in influencing yield at this period.

Petiole weight was the most important variable which affected fruit yield from July 16 to October 15, 1970 (Table 8). Tree-trunk circumference was the next most important variable, followed by petiole K. Petiole N was not significantly correlated with yield. Petiole weight accounted for 77.6 percent of the yield variance, while tree-trunk circumference in addition to petiole weight accounted for 86.3 percent. Because of the dominant influences of petiole weight and tree-trunk circumference on yield in the July period (Table 8), as compared to the

**Table 7. The effect of the indicated variable in accounting for the variance of fruit yield from 2/19/70 to 6/4/70 and the standard partial regression coefficients of the significant variables**

| Independent variables[x] | $r^2$ or $R^2$ | F of the indicated variable[y] | | | | Standard partial regression coefficients | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | $N^2$ | T | P | N | $N^2$ | T | P |
| N | .625 | 46.6** | | | | | | | |
| N, $N^2$ | .757 | | 14.79** | | | | | | |
| N, $N^2$, T | .843 | | | 14.25** | | | | | |
| N, $N^2$, T, P | .882 | | | | 8.20** | +2.880 | −2.533 | +0.318 | +0.303 |

$$Y = -265.11 + 315.72N - 120.38N^2 + 1.91T + 0.38P$$

[x]Variables: N = % petiole N on December 16; T = tree-trunk circumference on February 3, 1970; P = fresh weight of petiole on December 16, 1969.

[y]Significance: ** = 1% level.

**Table 8. The effect of the indicated variable in accounting for the variance of fruit yield from 7/16/70 to 10/15/70 and the standard partial regression coefficients of the significant variables**

| Independent variable[x] | $r^2$ or $R^2$ | F of the last variable[y] | | | | | Standard partial regression coefficient | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | $N^2$ | P | T | K | P | T | K |
| N | .349 | 14.99** | | | | | | | |
| N, $N^2$ | .405 | | 2.56ns | | | | | | |
| P | .776 | | | 97.17** | | | | | |
| P, N | .784 | 0.94ns | | | | | | | |
| T | .712 | | | | 69.04** | | | | |
| P, T | .863 | | | | 17.14** | | | | |
| P, T, K | .912 | | | | | 14.67** | +.795 | +.450 | +.331 |

$$Y = 106.52 + 0.44P + 1.48T + 6.36K$$

[x]Variables: N = % petiole N at 7/14/70; P = petiole wt at 7/14/70; T = tree-trunk circumference at 7/21/70; K = % petiole K at 7/14/70.

[y]Significance: ** = 1% level; ns = not significant.

influences of these two factors in the December period (Table 7), it appears that the trees were under moisture stress in the July period.

### Relations of Some Variables to Petiole N

The N application rates accounted for 70.9 percent of the petiole N variance in the December 16 samples (Table 9). The petiole N concentrations at this date were also dependent upon the petiole N concentrations on October 7, 1969. Petiole K also affected petiole N. Petiole moisture did not affect petiole N.

In petioles sampled on July 14, 1970, the N application rates accounted for 86.4 percent of the petiole N variance (Table 10). The relation between these two factors was much better at this period than in December, probably because of the influences of seasonal climatic factors. The yield prior to July 14 lowered petiole N somewhat. Petiole moisture did not influence petiole N as in the December analysis.

### Relation of Petiole N to Fruit Yield

Figure 1 presents the relation of petiole N concentrations to fruit yield and the determination of the N critical level. From the second degree polynomial curve of best fit, maximum yield was determined at 1.40 percent N, while 95 percent and 90 percent of the maximum yield were determined at 1.23 percent and 1.17 percent N, respectively. The mean petiole P and K concentrations in all treatments were above their respective tentative critical levels *(3, 4)*.

**Table 9. The effect of the indicated variable in accounting for the variance of petiole N on 12/16/69, and the standard partial regression coefficients of the significant variables**

| Independent variable[x] | $R^2$ | F of the indicated variable[y] | | | | | Standard partial regression coefficient | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Nr | $(Nr)^2$ | W | N | K | Nr | $(Nr)^2$ | N | K |
| Nr, $(Nr)^2$ | .709 | $22.10^{**}$ | $7.85^{**}$ | | | | | | | |
| Nr, $(Nr)^2$, W | .709 | | | $.03^{ns}$ | | | | | | |
| Nr, $(Nr)^2$, N | .774 | | | | $7.50^{*}$ | | | | | |
| Nr, $(Nr)^2$, N, K | .809 | | | | | $4.51^{*}$ | +1.06 | −0.62 | +0.51 | +0.21 |

$$Y = 0.056 + 0.930Nr - 0.913(Nr)^2 + 0.620N + 0.071K$$

[x]Variables: Nr = lb. N/tree/12 weeks; W = % petiole moisture at 12/16/69; N = % petiole N at 10/7/69; K = % petiole K at 12/16/69.

[y]Significance: ** = 1% level; * = 5% level; ns = not significant.

**Table 10. The effect of each indicated factor in accounting for the variance of petiole N on 7/14/70, and the standard partial regression coefficients of the significant variables**

| Independent variable[x] | $R^2$ | F of the indicated factor[y] | | | | | | | Standard partial regression coefficient | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Nr | $(Nr)^2$ | P | W | T | K | Y | Nr | $(Nr)^2$ | Y |
| Nr, $(Nr)^2$ | .864 | 60.4** | 22.5** | | | | | | | | |
| Nr, $(Nr)^2$, P | .874 | | | $2.0^{ns}$ | | | | | | | |
| Nr, $(Nr)^2$, W | .866 | | | | $.04^{ns}$ | | | | | | |
| Nr, $(Nr)^2$, T | .865 | | | | | $0.2^{ns}$ | | | | | |
| Nr, $(Nr)^2$, K | .865 | | | | | | $0.2^{ns}$ | | | | |
| Nr, $(Nr)^2$, Y | .882 | | | | | | | $4.0^{z}$ | +2.41 | −1.51 | −0.17 |

$$Y = 4.53 + 1.98Nr - 1.51(Nr)^2 - 0.00087Y$$

[x]Variables: Nr = lb. N/tree/12 weeks; P = petiole weight; T = tree-trunk circumference; Y = lb. fruit/tree harvested from 8/14/69 to 7/9/70.

[y]Significance: ** = 1% level; z = 10% level; ns = not significant.

## Relation of N Application Rates to Concentrations of Petiole N

Figure 2 indicates that to attain a petiole N level of 1.23 percent, which is associated with 95 percent of the maximum yield (Figure 1), an N application rate of 0.30 lb/12 weeks is required for each tree. To attain a petiole N level of 1.17 percent, which is associated with 90 percent of the maximum yield, an application rate of 0.19 lb/12 weeks is required for each tree.

## Fertilizer Recommendations

The N levels determined at Puna *(5)* and in this study were conducted under contrasting climatic, soil, and cultural conditions, yet were determined to be about the same. Therefore, N fertilizer recommendations based on a single critical N level may be made to papaya trees grown in all parts of the state of Hawaii. Since better results were obtained at Puna than in this study, the recommendation is in favor of the determination at Puna. Hence, a petiole N level at 1.28 percent N, which is associated with 95 percent of the maximum yield, is recommended to growers in Hawaii.

To attain this N level in the petiole of papaya trees grown in areas under similar climatic, soil, and cultural conditions as at Waimanalo,

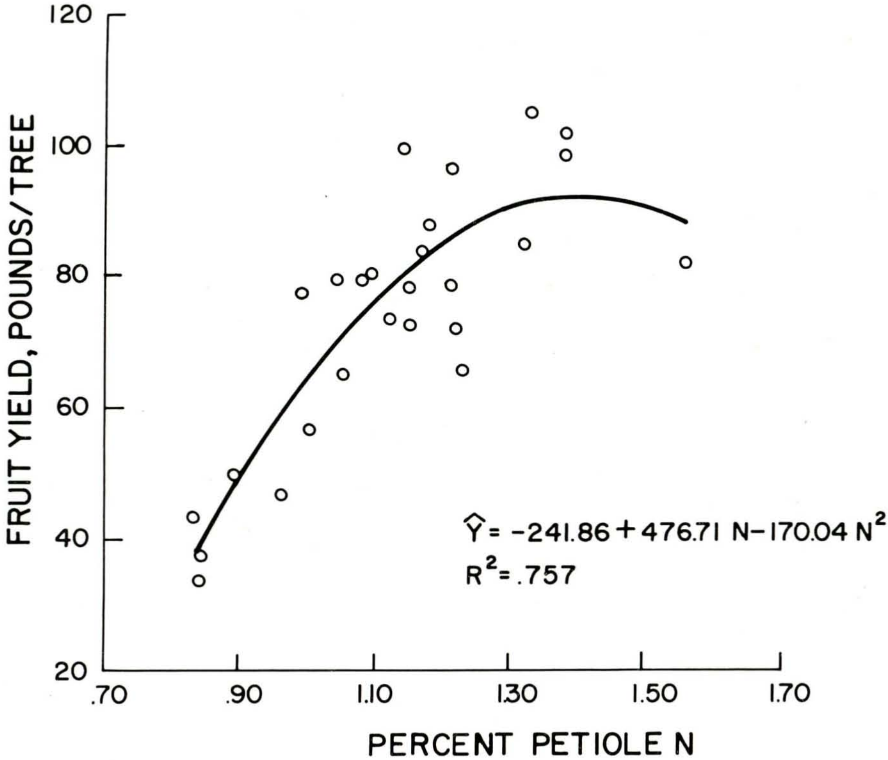


Fig. 1. The relation of petiole N to fruit yield. Maximum yield was attained at 1.40% N. Yield was taken from February 17, 1970 to June 4, 1970.

N fertilizer at the rate of 0.30 lb/12 weeks per tree is required. A rate less than this would be required if moisture stress is less.

**General Discussion on Water Relations of Papaya**

In this study, the growth rate of the tree-trunk circumference (Table 2), petiole weights (Table 3), fruit yield (Table 8), and petiole N concentrations (Table 6) were lowered during the summer because the plants may have been under moisture stress. The evidence that the plant water status was inadequate would have been unequivocal if there was a critical moisture level for papaya.

An attempt to select a moisture index tissue for papaya in an irrigation experiment was not entirely successful *(1)*. In that study, when the petiole at the same stage of maturity as our nutrient index tissue was

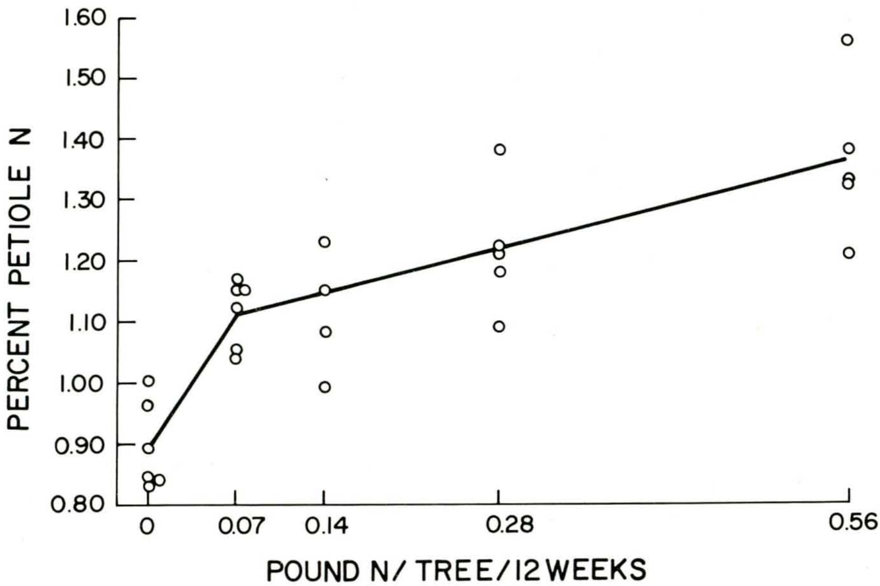


Fig. 2. The relation of N application rates to N concentrations of petioles sampled on December 16, 1969.

used as the moisture index tissue, it was found to be unsuitable. The blade, at a similar stage of maturity as the petiole, was also unsuitable. Only a younger petiole than the nutrient index tissue appeared promising, but because the range in moisture in this tissue was narrow, it has not been used.

In the N study at Puna *(5)* and in this study, petiole moisture concentrations in our nutrient index tissue did not correlate well with petiole N concentrations. This is in contrast to the study *(6)* in sugarcane in which Clements reported that leaf blade N and sheath moisture were highly correlated. An explanation to this contrasting result is not available at this time, but it may be related to the fact that the sugarcane plant is primarily vegetative and does not bear any fruits, while a papaya plant bears fruits continuously, more or less, after it reaches the fruiting stage. Fruits apparently may be a better moisture indicator than the petioles in papaya.

Another alternative to using a leaf moisture concentration as an indicator to the moisture status of the papaya plant may be the use of the tree-trunk growth rate (Table 2) or the use of the petiole weight (Table 3). Verner et al. *(11)* have used the tree-trunk growth, as measured by a dendrometer, in scheduling irrigation of apple and prune trees in Idaho. Uriu et al. *(10)* demonstrated the sensitivity of the tree-trunk growth to irrigation frequencies in almonds. In papaya, there is a possibility that the tree-trunk growth rate or the weight of the petioles can be used as an indicator of the moisture status of the plant.

## SUMMARY

Flowering and fruiting papaya trees were supplied N fertilizer at five rates at Waimanalo. Trees were furrow-irrigated at 10-day intervals from March 2 to November 28, 1969 and on March 2 to October 14, 1970.

The critical petiole N level determined by data in the December period was essentially the same as that reported earlier at Puna.

The growth rate of the tree-trunk circumference and the weight of the petioles were substantially lower in the summer than in the winter, which suggested that the plants were under moisture stress in the summer.

The petiole N concentrations were lower in petioles sampled during the summer than during the winter, again suggesting that the trees were under moisture stress during the former period. In addition to moisture stress, high K may have lowered petiole N somewhat.

Because the trees were probably under moisture stress during the July period, the relation between petiole N concentrations and fruit yield during this period was poor. As a result, it was not possible to determine the critical petiole N level at this period.

Petiole weight was the most important variable which was correlated with fruit yield during the July period. Tree-trunk size and petiole K were also significantly correlated with fruit yield during this period.

Petiole N, tree-trunk size, and petiole weight were significantly correlated with fruit yield during the December period. Petiole weight and tree-trunk size were, however, less important in affecting yield during the December period than the July period.

The N application rate, petiole N in October, and petiole K in December were correlated with petiole N in December. The N application rate was the most important variable which was correlated with petiole N in July, although crop-load was of lesser but significant importance. The N application rate was much more important during the July period than the December period.

The amount of N fertilizer required to attain the critical N level was also made. This rate, however, applies only to fruiting papaya trees grown under similar climatic and soil conditions as at Waimanalo.

Some aspects of the water relations of papaya were discussed.

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